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Type and extent of ground disturbance following skidder logging in Newfoundland and Labrador

by
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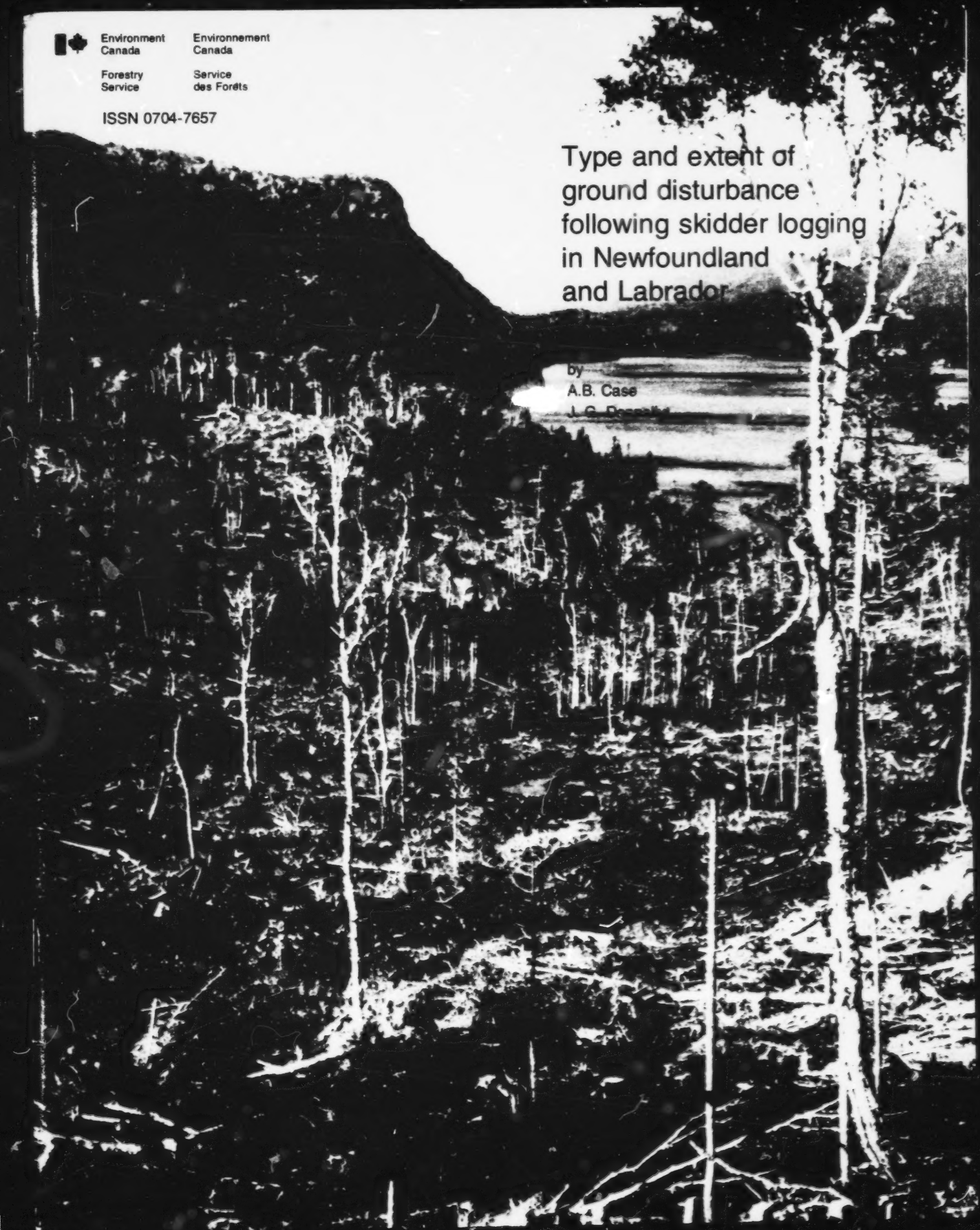

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TYPE AND EXTENT OF GROUND DISTURBANCE FOLLOWING SKIDDER LOGGING IN NEWFOUNDLAND AND LABRADOR

by A.B. Case and J.G. Donnelly

NEWFOUNDLAND FOREST RESEARCH CENTRE
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ABSTRACT

Six cutovers throughout Newfoundland and Labrador were investigated one year after logging to determine the type and extent of ground disturbance associated with skidder logging. Data on bulldozed areas were collected by direct measurement; and on unbulldozed portions of cutovers using two hundred 20 m^2 sample plots along parallel line transects.

Bulldozing exposed mineral soil on 5.9% of the cutover area and left debris on 3.7%, for a total disturbance of 9.6%. Greatest bulldozer disturbance was attributable to extraction roads (including skidtrails). Bulldozing on winter logging operations caused 50-60% less disturbance than on summer-logged areas. The amount of Newfoundland's forest land area that is potentially lost to fibre production through bulldozing was calculated to be 1500-2000 ha/yr. In terms of productivity, the average loss in allowable annual cut was estimated at 0.15 m^3/ha/yr.

Ground disturbance on unbulldozed portions of cutovers was patchy. About 14% of the area suffered moderate to heavy disturbance of which 3% was exposed mineral soil. About 30% of the unbulldozed cutover suffered some degree of compaction with greatest compaction on unbulldozed landings and skidtrails where it appeared to be limiting successful establishment of softwood regeneration. Up to 4000 ha annually are potentially affected in this manner. Reductions in allowable annual cut due to compaction may amount to 0.36 m^3/ha/yr in second-growth stands.

Slash cover was relatively moderate and uniformly distributed on most cutovers. Dense accumulations of slash occupied a mean of 29% of the unbulldozed cutover area.

RÉSUMÉ

On a fait une étude sur six terrains déboisés à Terre-Neuve et au Labrador, une année après l'abattage, pour déterminer le genre et le degré de retournement de sol qui a accompagné l'abattage du bois à la débusqueuse. On a recueilli des données sur les régions bulldozées au moyen de mesurages directs, tandis que sur les portions de terrain déboisé nonbulldozées on s'est servi de deux cents parcelles-échantillons de 20 m^2 le long des lignes d'estimation parallèles.

Le travail au bulldozer a exposé le sol minéral sur 5.9% de la surface du terrain déboisé et a laissé des débris sur 3.7%, pour un retournement total de 9.6%. Le retournement le plus important, résultant du travail au bulldozer, a été causé par la construction des chemins

d'extraction (y compris les chemins de débusquage). Le travail au bulldozer effectué pendant l'abattage d'hiver a causé de 50 à 60% moins de retournement de sol que ce même genre de travail effectué pendant l'abattage de certaines régions pendant l'été. La perte potentielle par bulldozage de sol forestier de Terre-Neuve, pour ce qui est de la production de fibres, est évaluée à 1500-2000 hectares par année. En termes de productivité, la perte moyenne au cours d'une coupe annuelle permise, a été estimée à 0.15 m^3/hectare/année.

Le retournement du sol sur les parcelles de terrain déboisé nonbulldozées a eu lieu de place en place et de façon inégale. Environ 14% de la surface a subi un retournement de sol qui va de modéré à fort; de ces 14%, 3% était du sol minéral exposé. Environ 30% du terrain déboisé nonbulldozé a subi un certain degré de compactage. Le compactage s'est avéré le plus fort dans les jetées nonbulldozées et dans les chemins de débusquage. Là, il semblait alors limiter les chances de succès de régénération de bois mous. Chaque année, jusqu'à 4000 hectares sont potentiellement affectés de cette manière. Les réductions dans la coupe permise annuellement dues au compactage peuvent se chiffrer à 0.36 m^3/hectare/année dans les peuplements de repousse.

L'étendue des déchets a été relativement raisonnable et distribuée d'une façon uniforme sur la plupart des terrains déboisés. De fortes accumulations de déchets ont occupé une moyenne de 29% de la surface du terrain déboisé nonbulldozé.

TYPE AND EXTENT OF GROUND DISTURBANCE FOLLOWING SKIDDER LOGGING IN NEWFOUNDLAND AND LABRADOR

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INTRODUCTION

Extensive areas of even-aged softwood forest occur throughout Newfoundland and Labrador. These forest stands are normally harvested by clearcutting, and on most operations rubber-tired skidders are used to transport wood from the felling area to roadside landings. Forest managers in government and industry have expressed concern over the damaging impacts of skidder logging on soil conditions and on the future productivity of logged sites. Such impacts have been investigated extensively in western Canada and the United States (Dyrness 1965; Froelich 1973; Hatchell et al. 1970; Steinbrenner and Gessel 1955), and to a lesser degree in eastern Canada (Ellis and Mattice 1974; Frisque et al. 1978; Weetman et al. 1973). Such information is lacking for Newfoundland and Labrador where most work on cutovers to date has been restricted primarily to determining the adequacy of regeneration following harvesting (Hall and Richardson 1973; Richardson 1974, 1975; Richardson and Hall 1973a, 1973b; Robinson 1970).

Knowledge of ground conditions following logging is an important prerequisite to sound forest management, if one considers that site protection and conservation are essential to the growing of trees. Furthermore, an understanding of the types and magnitude of ground disturbance lends to improved planning of operations for reducing damaging impacts to terrestrial and aquatic ecosystems.

The present study was designed to obtain precise information on the type and extent of ground disturbance created by skidder logging operations in even-aged softwood stands. It is the first of several studies to be undertaken to investigate the effects of different logging methods and systems on soil surface conditions.

THE STUDY

Description of Study Areas

Six cutovers located throughout Newfoundland and Labrador were examined one year after logging (Figure 1). All areas were harvested by clearcutting and using rubber-tired skidders to transport tree-lengths

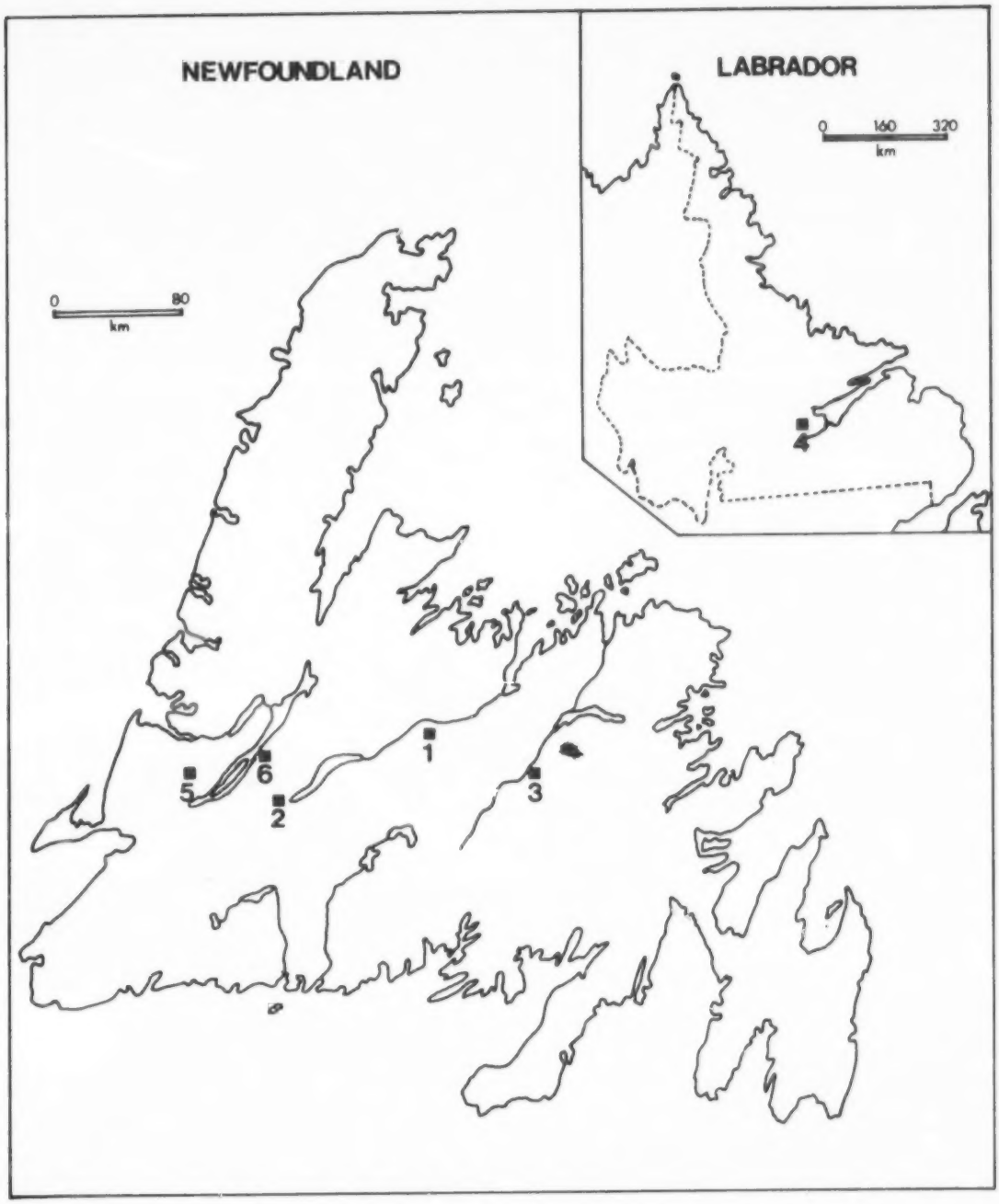


Figure 1. Map of Newfoundland and Labrador (inset) showing location of study areas. 1 - Pamehac Lake; 2 - Lloyds River; 3 - Greenwood Brook; 4 - Peter's River; 5 - Stag Lake; 6 - Grand Lake.

from the felling area to roadside landings. Steep areas along streams and lakes, wetland borders, and unmerchantable second-growth trees were not harvested. For purposes of this study such residual patches of uncut wood were not considered part of the cutover area.

The main species harvested were balsam fir (Abies balsamea (L.) Mill.) and black spruce (Picea mariana (Mill.) B.S.P.) with lesser amounts of white spruce (Picea glauca (Moench) Voss). Frequent residual white birch (Betula papyrifera Marsh.) were encountered on most cutovers.

Minor vegetation on cutovers consisted of Rubus idaeus L., Clintonia borealis (Ait.) Raf., Cornus canadensis L., Sphagnum spp., and Hylocomium spp. Polytrichum spp. and graminoids had begun to colonize small areas of exposed mineral soil at several locations. Small patches of lichens were observed on the Peter's River study area (Figure 1).

Aerial photographs and maps of the areas, along with cutting and operational data, were provided by Bowater Newfoundland Limited, Price (Nfld.) Pulp and Paper Limited, and the Department of Forest Resources and Lands. Information on topography and land types was obtained from aerial photographs and 1:50,000 topographic map sheets, by field observations, and by extrapolating from the results of biophysical studies for the Corner Brook area (Wells et al. 1972), the Badger-Diversion Lake area (Wells and Roberts 1973), and the Lake Melville area (Bajzak 1973). This information is summarized in Table 1.

Hand texturing gave an estimate of soil drainage and textural conditions. While general topographic conditions were highly variable among areas, there appeared to be only minor differences in soil texture and drainage. Soils on study cutovers were, for the most part, sandy to silty loam tills having moderate drainage. The exceptions were at Greenwood Brook and Peter's River where loams were somewhat clayey and thus tended to be less well drained.

Estimates of erosion hazard and restrictions to equipment usage were based on observations of soil texture, drainage conditions, and erosional features (e.g. rills, slumps, gullies) on each cutover.

Study Procedures

Two distinct cutover strata were recognized on the basis of intensity of machine disturbance:

Bulldozed cutover: bulldozed roads, skidtrails, and landings and exposed mineral soil and grubbing debris associated with these structures;

Unbulldozed cutover: all remaining portions of cutovers including unbulldozed skidtrails and landings.

Table 1. General characteristics of the six study locations.

Study location	Area of study cutover (ha)	Logging season[1]	Elevation (m)	Species suitability[2]	General topography	Slope (%)	Soils[3]	Drainage	Erosion hazard	Equipment restriction
Pamehac Lake	403	S	150-180	bF,bS,wB	Flat-rolling	2-5	Mod.stony SiL till	Moderate-good	Slight-moderate	Slight-moderate
Lloyds River	152	S	150-300	bF,wS,bS,wB	Hilly	20-40	Mod.stony SaL till	Moderate-good	Moderate	Moderate
Grand Lake	164	S	90-360	bF,wS,bS wB,wP	Hilly	20-40	Mod.stony SaL till	Moderate-good	Moderate	Moderate
Greenwood Brook	172	F	120-150	bF,bS,wS wB,tA	Rolling	2-10	Mod.stony SaClL till	Moderate-poor	Moderate	Moderate
Stag Lake	182	W	150-300	bF,bS,wS,wB	Hilly	5-40	Mod.stony SiL till	Moderate-good	Moderate	Moderate
Peter's River	168	W	90-120	bF,bS,wS	Flat-rolling	2-10	SaClL till	Poor-moderate	Moderate	Moderate-severe

[1]Logging season: S - Summer; F - Fall; W - Winter.

[2]Species suitability: species which the area is suited to grow naturally.
bF - balsam fir; bS - black spruce; wB - white birch; wS - white spruce; wP - white pine (Pinus strobus L.); tA - trembling aspen (Populus tremuloides Michx.).

[3]Soils: SiL - silt loam; SaL - sandy loam; SaClL - sandy clay loam.

Bulldozed Cutover

Roads

Three classes of road were identified as follows:

Primary hauling roads: routes with life-spans of several years which provide access to a number of cutovers.

Secondary hauling roads: main routes within cutovers which collect traffic from feeder or spur roads and channel it onto primary hauling roads.

Extraction roads: feeder or spur roads (short, dead-end or circuitous roads with limited life-spans of a few weeks during the hauling season, which provide access to landings throughout the cutover area) and bulldozed skidtrails.

The total length of road network in each class was measured. Only those portions of roads within the cutover area itself were considered. At 160 m intervals along each road a line transect was established at right angles to the center line, and the intercepts occupied by each of the following cross-sectional features were measured (Figure 2):

(a) road surface including shoulders

(b) associated bare soil excluding road surface and shoulders

(c) bulldozed grubbing-debris piles.

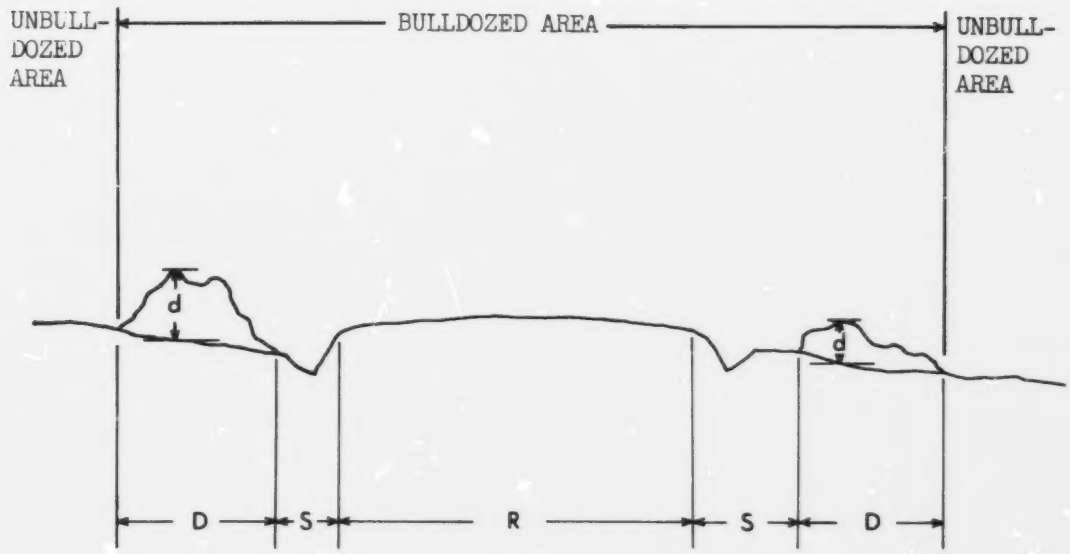
At each transect location the average depth of bulldozed debris was measured at the highest portion of the piles. This information combined with data for average width and length of piles was used to estimate debris volume.

Landings

The areas of rectangular landings were determined using average length and average width. Irregularly shaped landings were measured as closed traverses and areas were calculated by the method of latitudes and departures. Grubbing-debris piles surrounding bulldozed landings were measured at six regularly spaced intervals. At each location both the width and the depth of debris at the highest portion of the pile were measured. Estimates of debris volume were calculated as for roadside debris.

Unbulldozed Cutover

This part of the study employed parallel line transects with 20 m^2 plots at 80 m intervals. Spacing of transects varied from 80 m to 220 m, depending upon the size of cutover, thus ensuring a minimum of



R - width of road surface including shoulders

S - total width of associated bare soil

D - total width of grubbing debris piles

d - depth of grubbing debris

Figure 2. Illustration of cross-sectional measurements taken at 160 m intervals along roads.

200 plots per study area. Transects were run perpendicular to an established baseline. Plot locations were determined by chaining to the beginning of the plot. A 2 m stick was used to establish a 2 m by 10 m plot, consisting of five 2 m square subplots, with its long axis along the transect.

In general, procedures followed those of Garrison and Rummell (1951) and Dyrness (1965), with minor modifications to permit inclusion of additional information.

The following data were recorded on each subplot and grouped for the complete plot:

(a) The proportion of unbulldozed cutover occupied by each of 4 categories and 13 classes of disturbance:

(i) *Absent or virtually absent*

UML - undisturbed mosses and litter
SSML - mosses and litter slightly scuffed

(ii) *Light*

FE - exposure of the 'F' horizon
RUC - mosses and portions of the LFH layer torn up in chunks but redeposited uninverted in place

(iii) *Moderate*

UIC - mosses and portions of the LFH layer torn up in chunks and not redeposited in place, or if redeposited in place then inverted

HE - exposure of the 'H' horizon

SMSE - shallow exposure of mineral soil to a depth of 5 cm or less

MIX - intimate mixture of litter, mosses, organic matter and mineral soil

SMSD - shallow mineral soil deposits on slash and ground to depth of 5 cm or less

(iv) *Heavy*

DMSE - deep exposure of mineral soil to a depth exceeding 5 cm

DMSD - deep mineral soil deposits on slash and ground to a depth exceeding 5 cm

M - muck caused by passage of skidder or tractor over wet soils

E - erosion feature (e.g. rills, gullies).

(b) An estimate of the proportion of unbulldozed area that was apparently compacted by each of the following:

(i) machine trails (skidtrails and tractor trails)

(ii) landings

(iii) cull logs including residual fallen trees. The degree of compaction was not determined.

(c) An estimate of the proportion of unbulldozed area occupied by each of four categories of slash density:[1]

(i) absent - < 115 m^3/ha

(ii) light - 115-635 m^3/ha

(iii) moderate - 636-1250 m^3/ha

(iv) heavy - > 1250 m^3/ha

RESULTS

Disturbance Caused by Bulldozing

The proportion of bulldozer disturbance from skidder logging operations on the six clearcut areas is shown in Table 2. The highest figures were recorded at Lloyds River and Greenwood Brook where bulldozer disturbance was 1.6 times the mean for all areas. At Pamehac Lake

[1]Relative slash density expressed in m^3/ha was calculated as the product of average depth (cm) and percent cover.

Table 2. Type and extent of bulldozer disturbance associated with skidder-logging operations, by operating season and location.

Bulldozer-associated disturbance	Operating Season and Location						
	Summer			Fall	Winter		
	Pamehac Lake	Lloyds River	Grand Lake	Greenwood Brook	Stag Lake	Peter's River	Total
	% of cutover area						
PRIMARY HAULING ROADS							
- surface	0.7	0.8	0.7	0.0	0.0	0.0	0.4
- associated mineral soil	1.1	1.6	0.4	0.0	0.0	0.0	0.6
- associated grubbing debris	0.8	0.9	1.0	0.0	0.0	0.0	0.5
TOTAL	2.6	3.3	2.1	0.0	0.0	0.0	1.5
SECONDARY HAULING ROADS							
- surface	0.5	1.1	0.0	0.6	0.4	0.5	0.5
- associated mineral soil	0.7	1.5	0.0	0.3	0.3	0.3	0.5
- associated grubbing debris	0.9	1.2	0.0	1.4	0.3	0.4	0.8
TOTAL	2.1	3.8	0.0	2.3	1.0	1.2	1.8
EXTRACTION ROADS							
- surface	1.8	1.3	1.8	3.5	0.6	0.7	1.6
- associated mineral soil	2.1	1.7	1.1	2.4	0.3	0.4	1.5
- associated grubbing debris	2.4	1.5	2.1	6.7	0.6	0.4	2.3
TOTAL	6.3	4.5	5.0	12.6	1.5	1.5	5.4
BULLDOZED LANDINGS							
- surface	0.0	2.9	0.4	0.5	2.1	0.2	0.8
- associated grubbing debris	0.0	0.7	0.1	0.1	0.0	0.1	0.1
TOTAL	0.0	3.6	0.5	0.6	2.1	0.3	0.9
TOTAL MINERAL SOIL EXPOSURE	6.9	11.6	4.5	7.4	3.7	2.2	5.9
TOTAL BULLDOZER DISTURBANCE	11.0	15.2	7.6	15.5	4.6	3.0	9.6

disturbance from this source was 1.1 times the mean. Least bulldozer disturbance was at Peter's River where disturbance was 0.3 times the mean, followed by Stag Lake and Grand Lake with disturbances of 0.5 times and 0.8 times the mean, respectively.

Extraction roads were present on all study areas and comprised the highest amount of bulldozer disturbance overall. Greatest disturbance by extraction roads was on the fall-logged area at Greenwood Brook; least disturbance was on the winter-logged areas at Stag Lake and Peter's River. About 40% of the disturbance associated with extraction roads was from accumulations of grubbing debris along the sides of roads and skidtrails.

About 20% of the total bulldozer disturbance was from secondary hauling road construction. The highest proportion of these roads was recorded at Lloyds River followed by Greenwood Brook and Pamehac Lake. Secondary hauling roads were absent on the Grand Lake cutover.

Primary hauling roads were present on only the summer-logged areas. Most of the disturbance on the Pamehac Lake and Lloyds River areas was 'associated mineral soil' (ditches, cut banks, backslopes, fill slopes, etc.). At Grand Lake nearly 50% of the primary hauling-road-related disturbance was 'associated grubbing debris'.

Bulldozed landings were present on all but the Pamehac Lake area where wood had been piled on the unbulldozed cutover at roadside. On all landings, the actual operating surface accounted for the most disturbance, while grubbing debris contributed about 20% of the total disturbance on most areas. Grubbing debris was not recorded at Stag Lake since it had been incorporated with mineral soil into the landing surfaces.

The volume and distribution of debris associated with bulldozing are depicted in Figure 3. Highest volumes were recorded on summer- and fall-logged areas. Debris volumes at Pamehac Lake, Lloyds River and Grand Lake were 187 m^3/ha, 278 m^3/ha and 142 m^3/ha, respectively. At Greenwood Brook the mean volume of debris was 303 m^3/ha. Debris associated with bulldozed landings appeared relatively insignificant except at Lloyds River where all 4 sources of debris were equally important. Debris volumes were low on the winter-logged areas at Stag Lake and Peter's River.

Disturbance on Unbulldozed Portions of Cutovers

Ground Disturbance

Ground disturbance on unbulldozed portions of cutovers was generally caused by skidding operations. The degree of disturbance on each cutover is shown in Table 3. On average only 20% of the area of

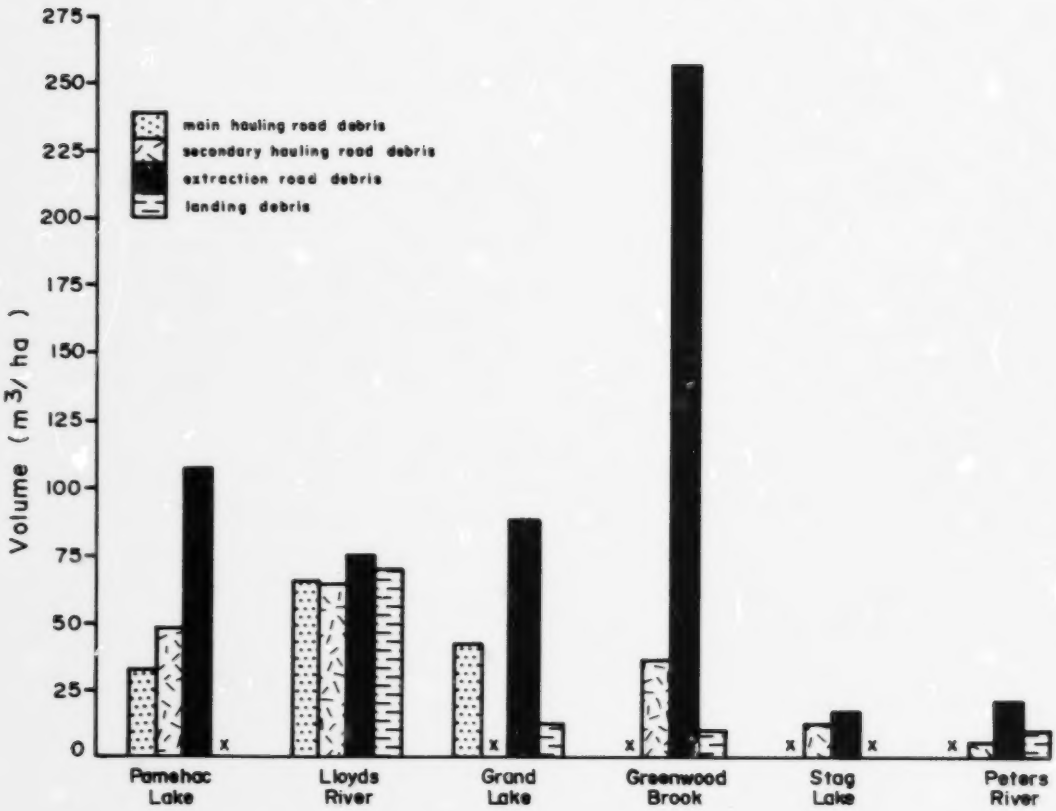


Figure 3. Volume and distribution of debris associated with bulldozing on study cutovers. 'x' denotes absence of feature.

Table 3. Degree of ground disturbance on unbulldozed portions of cutovers.

Degree of disturbance	% of unbulldozed area						
	Summer			Fall	Winter		
	Pamehac Lake	Lloyds River	Grand Lake	Greenwood Brook	Stag Lake	Peter's River	All areas
Light	4.3	4.2	3.9	17.2	2.0	8.6	6.1
Moderate	10.0	12.7	7.4	16.3	7.5	12.5	10.7
Heavy	2.1	4.0	2.6	6.1	4.0	2.9	3.3
Absent or virtually absent	83.6	79.1	86.1	60.4	86.5	76.0	79.9

cutovers was disturbed. The most noticeable effects were on the fall-logged area at Greenwood Brook where nearly 40% of the unbulldozed cutover was disturbed and more than 22% of the area suffered moderate to heavy disturbance. Overall there was little difference in the levels of disturbance between winter-logged and summer-logged areas.

Exposure of the F horizon (FE) (Figure 4) was the most common form of light disturbance (Table 4). Moderate disturbance occurred mostly as intimate mixtures of litter, mosses, organic matter and mineral soil (MIX) (Figure 5). Chunks of organic layer that had been torn up and inverted (UIC) were also a common form of moderate disturbance on most areas. Deep exposure of the mineral soil layer beyond 5 cm (DMSE) was the dominant type of heavy disturbance on all but the flat to rolling areas at Pamehac Lake and Peter's River (Figure 6). Muck (M) caused by the passage of skidders over wet depressions was the most common heavy disturbance at Peter's River (Figure 7). M and DMSE occupied equal proportions of the Pamehac Lake cutover.

Compaction

The area of compacted surface was low on most cutovers (Table 5). The extent of compaction was least on the steep areas at Grand Lake and Stag Lake. It was greatest at Greenwood Brook and Pamehac Lake, and at both areas was manifested in numerous unbulldozed machine trails and landings which together occupied 50.9% and 38.4%, respectively, of the unbulldozed cutover. Cull logs occupied an appreciable proportion of all cutovers (Figure 8). Compaction from this source was greatest at Pamehac Lake and Stag Lake where 3.2% and 3.5%, respectively, of the area was affected.

Table 4. Type and extent of ground disturbance on unbulldozed portions of cutovers.

Operating location and season	Disturbance Type												
	Absent or virtually absent		Light		Moderate					Heavy			
	UML	SSML	FE	RUC	UIC	HE	SMSE	MIX	SMSD	DMSE	DMSD	M	E
	% of unbulldozed cutover												
Pamehac Lake (summer)	72.4	11.2	3.2	1.1	0.3	0.3	0.2	9.0	0.2	0.9	0.2	0.9	0.1
Lloyds River (summer)	74.6	4.5	3.6	0.6	0.3	0.6	0.0	11.0	0.8	2.5	0.2	0.8	0.5
Grand Lake (summer)	84.6	1.5	3.2	0.7	3.3	0.3	1.6	2.2	0.0	2.2	0.1	0.2	0.1
Greenwood Brook (fall)	51.6	8.8	15.9	1.3	3.0	1.2	1.6	10.0	0.5	3.1	0.9	1.9	0.2
Stag Lake (winter)	85.4	1.1	1.9	0.1	0.1	0.8	0.0	6.4	0.2	3.4	0.3	0.3	0.0
Peter's River (winter)	72.9	3.1	4.6	4.0	5.4	0.2	0.4	6.3	0.2	0.3	0.3	2.3	0.0

UML - undisturbed mosses and litter
SSML - moss and litter slightly scuffed
FE - exposure of the F horizon
RUC - mosses and LFH layer torn up in chunks but redeposited uninverted in place
UIC - mosses and portions of LFH layer torn up in chunks not redeposited in place or if in place are inverted
HE - exposure of H horizon
SMSE - shallow mineral soil exposure $\leq$ 5 cm
MIX - mixture of litter, moss, organic soil, mineral soil
SMSD - shallow mineral soil deposits $\leq$ 5 cm
DMSE - deep mineral soil exposure > 5 cm
DMSD - deep mineral soil deposits > 5 cm
M - muck
E - erosion

Figure 4. Light disturbance: exposure of the F horizon.

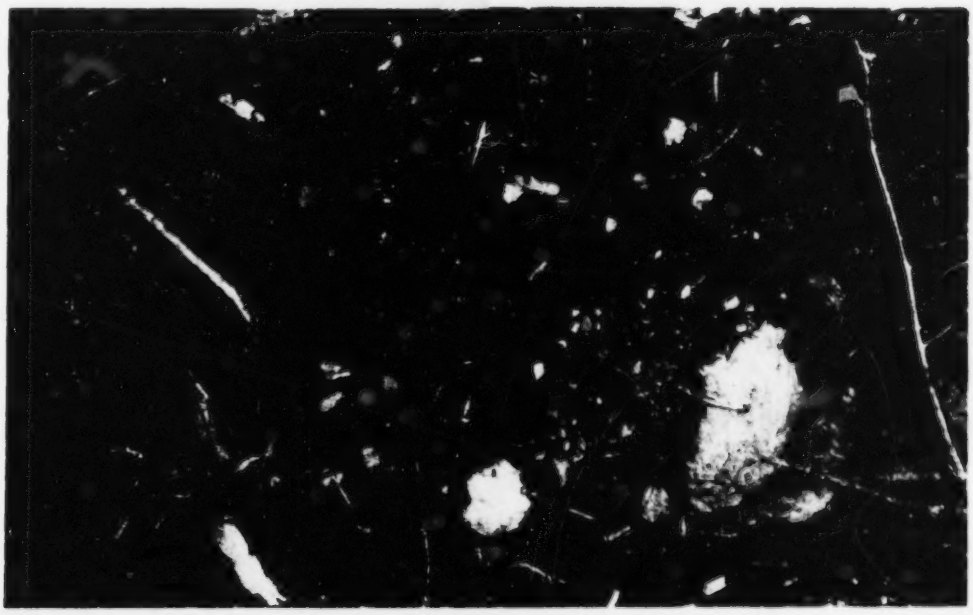


Figure 5. Moderate disturbance: intimate mixture of litter, mosses, organic matter and mineral soil.

Figure 6. Deep exposure of the mineral soil layer beyond 5 cm.

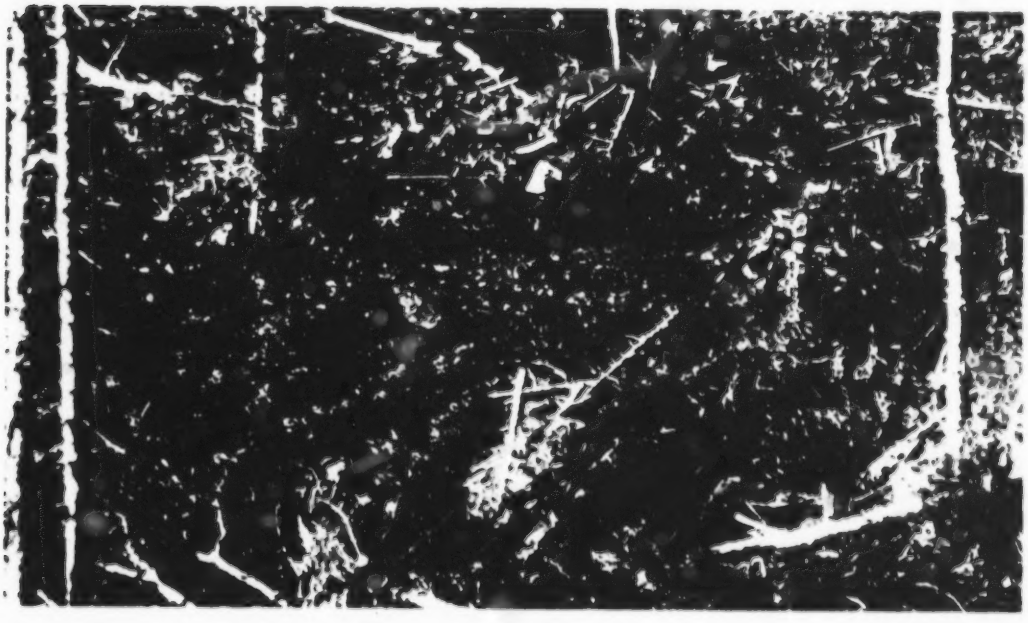


Figure 7. Muck caused by skidder passage over wet depressional terrain.

Table 5. Recorded cause of compaction occurring on unbulldozed portions of cutovers.

	% of unbulldozed area						
	Summer			Fall	Winter		
Cause	Pamehac Lake	Lloyds River	Grand Lake	Greenwood Brook	Stag Lake	Peter's River	All areas
Uncompacted	58.4	75.1	90.7	46.4	86.6	76.4	70.1
Machine trails	28.1	23.3	8.6	41.0	9.8	19.1	21.5
Landings	10.3	0.2	0.3	9.9	0.0	3.8	5.2
Cull logs	3.2	1.4	0.4	2.6	3.5	0.6	2.2

Figure 8. Cull logs on the winter-logged area at Stag Lake.

Slash Cover

Slash cover on unbulldozed portions of cutovers averaged 74.0%, with about equal proportions in the heavy and light classes, and a somewhat lesser amount in the moderate category (Table 6). Slash densities were generally higher on summer- and fall-logged areas than on winter-logged areas. The greatest extent of heavy and moderate slash combined was on the steep summer-logged area at Grand Lake, followed by Greenwood Brook, Lloyds River and Pamehac Lake. Least extent of slash in these two categories combined was at Stag Lake and Peter's River.

Table 6. Extent of slash cover on unbulldozed portions of cutovers by slash density class.

Slash density class	% of unbulldozed area						
	Summer			Fall	Winter		
	Pamehac Lake	Lloyds River	Grand Lake	Greenwood Brook	Stag Lake	Peter's River	All areas
Absent	26.0	27.4	13.8	20.8	39.4	26.5	26.0
Light	27.8	24.2	16.4	22.0	27.0	33.2	25.7
Moderate	19.6	18.3	19.7	21.1	17.0	20.5	19.3
Heavy	26.7	30.1	50.1	36.1	16.6	19.8	29.0

DISCUSSION

Bulldozing Disturbance and its Implications for Management

All study areas had appreciable bulldozing disturbance following skidder-logging operations. The data show that greatest exposure of mineral soil and accumulation of grubbing debris were associated with short-term extraction roads. Lesser amounts were attributable to landings and secondary and primary hauling roads.

There is no clear relationship between the levels of bulldozing disturbance and terrain conditions. However, the figures for landing disturbance indicate that this type of disturbance may be a function of topographic irregularity, since greatest development on study areas took

place in steeper terrain where "natural" landing space was limited. Based on the data and field observations it is the authors' judgement that bulldozer technology, especially the manner in which operators carry out construction, is a principal factor contributing to excessive bulldozing of soils. In several instances it appeared that disturbance was a product of inadequately controlled operational layout. Thus, from an environmental viewpoint, deliberate steps are required to educate both supervisors and operators in the efficient layout and construction of timber extraction networks in order to reduce ground disturbance.

Although the sampling of cutovers was limited it appears that winter logging operations produced less bulldozer disturbance than summer operations. The results of this study indicate a 50% to 60% reduction in the amount of disturbance on winter-logged cutovers. This agrees with observations by Klock (1975) in Washington, and by Smith and Wass (1976) in British Columbia.

The fall operation at Greenwood Brook produced a disproportionate amount of disturbance from extraction road development. Post-logging observations at the time of sampling showed this to have been made necessary by the excessively wet soil conditions which had created trafficability problems for normal off-road travel by skidders. The problem of excessive bulldozing on such poorly drained sites is not unexpected; however, the amount of disturbance can be minimized by fundamental planning to ensure that most such areas are logged during freeze-up periods.

Deep soil disturbance caused by bulldozing has long-term detrimental effects which could have serious implications for forest management. Most obvious is the removal of forest land from future production. Softwood regeneration was sparse and in most cases absent on exposed mineral soils and unconsolidated piles of grubbing debris. Case (1978) observed that softwoods were absent after 14 years on many bulldozed till soils in western Newfoundland, and that these sites were gradually being invaded by such pioneer vegetation as herbs (including graminoids) and shrubs. He attributed much of the problem to mineral soil exposure to depths beyond the fertile layers, extreme compaction, xeric growth conditions due to lack of shade, and surface instability due to water erosion from overland flow. Weetman et al. (1973) found a similar lack of new fir and spruce regeneration on skidtrails and strip roads on many fir cutovers logged by rubber-tired skidders elsewhere in eastern Canada. Observations on 30-to-40-year-old second growth balsam fir sites in central Newfoundland indicate that such conditions are likely to persist for the complete rotation (Figure 9).

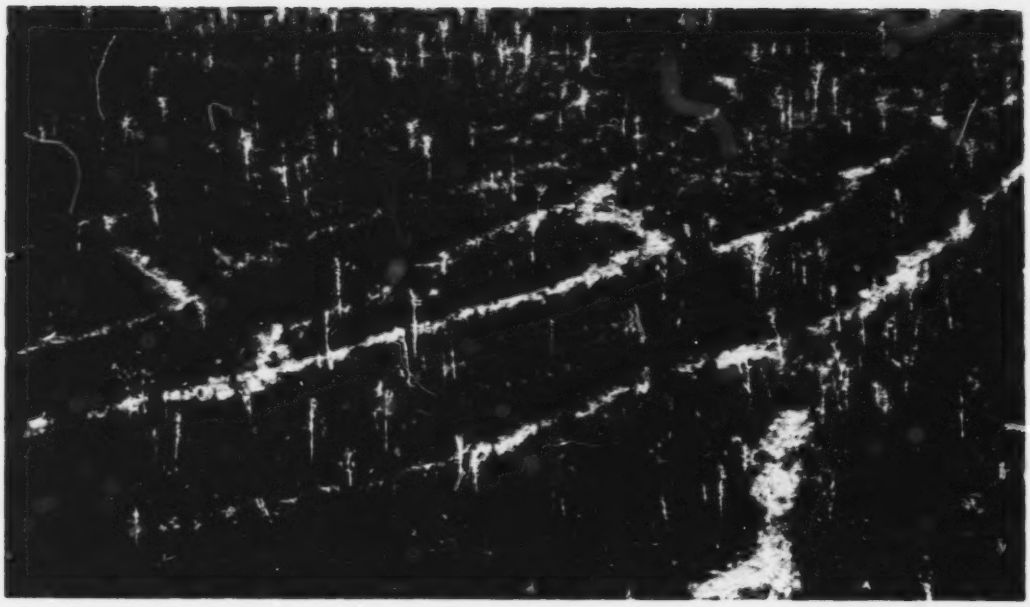


Figure 9. Second growth balsam fir stand in central Newfoundland showing inadequate softwood regeneration on old tractor roads.

By extrapolating the results of this study to the entire Province, the amount of forest land area potentially lost to fibre production by bulldozing is calculated to be 1500-2000 ha annually. In terms of productivity the average loss in allowable annual cut due to bulldozing alone is estimated to be 0.15 m^3/ha/yr^2 in second growth stands.

Some erosion was evident on several of the study cutovers. Sheet and rill erosion were the most common types of soil removal on roads and landing surfaces. Gully development was observed on steep (> 15% gradient) skidtrails near Stag Lake (Figure 10) and in roadside ditches in the vicinity of Lloyds River (Figure 11). Some site deterioration through removal of the fertile soil layers, and invasion of erosion and deposition areas by such opportunistic species as mosses and graminoids, was apparent on older cutovers.

Logging Disturbance on Unbulldozed Portions of Cutovers

Disturbance to unbulldozed portions of cutovers occurred only as small scattered patches. A mean of 14% of the unbulldozed surface was moderately to heavily disturbed. MIX disturbance, caused by skidding logs over the surface, was the most common form of moderate disturbance.

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[2] Assumes an average growth rate of 1.5 m^3 (solid)/ha/yr.

Figure 10. Gully erosion on a 3-year-old skidtrail in the vicinity of the Stag Lake study area.

Figure 11. Gullying in a roadside ditch in the vicinity of the Lloyds River study area.

Mineral soil was exposed on a mean of 3% of the unbulldozed cutover with about 73% of this being heavy DMSE and DMSD types of disturbance. Observation revealed that butt-end gouging and spinning of skidder tires, particularly in steeper areas, were the most common causes of mineral soil exposure. The small proportions of mineral soil exposed on unbulldozed portions of cutovers indicates that the skidder logging operations studied did not produce adequate scarification for successful establishment of softwood regeneration.

Individual patches of exposed soil were normally small and not contiguous, hence soil movement off-site was intercepted by intervening undisturbed areas and thus did not pose an environmental problem.

Muck development caused by repeated skidder passage over wet soils appeared to be the most severe type of disturbance. Though such disturbance was present on all study cutovers, it was greatest on the poorly drained areas at Greenwood Brook and Peter's River. Ponding of water on muck sites was clear indication that remoulding of soils by skidders caused significant alteration to soil drainage characteristics. On older cutovers site deterioration from such disturbance is manifested by unforested sedge-, grass-, or moss-covered patches in the developing stand.

The extent of compacted soil[3] was moderate on all unbulldozed cutovers except those at Pamehac Lake and Greenwood Brook where there were greater proportions of both unbulldozed landings and skidtrails. Compaction (except remoulding) on most unbulldozed areas is believed to be a temporary condition. However, observations on older cutovers indicate that while surfaces so affected will likely return to normal bulk densities within 5 to 7 years, softwood regenerations will often remain sparse and suppressed for much of the rotation period. On study areas the proportion of area compacted by unbulldozed landings and skidtrails combined was, on average, 26.7% which translates to about 4000 ha/yr on Newfoundland logging operations. In terms of productivity this implies a possible further mean reduction in allowable annual cut of up to 0.36 m^3/ha/yr.

Slash density was evenly distributed among the four slash density classes. Heavy logging slash, in the form of tops and cull logs, occupied a mean of 29% of the cutover area. In certain portions of the cutovers dense slash accumulations were extensive and will likely cause patchiness in the developing stand. However, in most instances slash did not appear to be a serious barrier to natural tree establishment, and should not be a matter of major concern to forest management dealing with natural regeneration on productive forest sites.

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[3]Includes remoulded soils or 'muck'.

The levels of disturbance on unbulldozed portions of cutovers appeared to be similar for summer- and winter-logged areas. The low levels of disturbance on such cutover indicate that any modification of the clearcutting method of tree harvesting will not likely result in any significant improvement in surface conditions outside the bulldozed areas. However, it is not possible to say at this point whether modification of cutting methods will improve stocking and distribution by increasing advance-growth survival on balsam fir sites, as suggested by Weetman et al. (1973), or by improving seed availability through modifying the size and configuration of cutovers on black spruce sites. This matter requires further investigation.

CONCLUSION

Skidder logging operations caused a variety of ground disturbance ranging from litter removal to deep exposure of the mineral soil. Types and extent of disturbance varied among locations depending on soil textural and drainage characteristics and on the season in which logging took place.

Bulldozing caused deep exposure of mineral soil on 9.6% of the area of cutovers. In terms of the total land area cut over in Newfoundland this translates to 1500-2000 ha of productive site which is removed from forest production annually. The potential loss in allowable annual cut from bulldozing alone is 0.15 m^3/ha/yr.

Greatest mineral soil exposure was associated with short term extraction roads and skidtrails. Lesser amounts were attributable to landing and secondary and primary hauling road construction. Bulldozing disturbance on winter-logged areas was 50-60% less than on summer-logged areas.

The problem of the effect of bulldozing on site quality is related both to bulldozing technology, i.e. the manner in which operators carry out construction, and to inadequately controlled operational layout. While some degree of soil disturbance through bulldozing is inevitable in logging, it can be reduced by educating both supervisors and operators in the efficient layout and construction of timber extraction networks.

Disturbance on unbulldozed portions of cutovers occurred as scattered patches of exposed mineral soil, compaction and slash accumulations. Individual patches of exposed soil were small and not contiguous and thus did not pose an environmental problem.

Greatest ground disturbance to unbulldozed areas resulted from summer and fall operations on poorly drained soils. Such operations caused site damage by remoulding the soils and compacting them thus

disrupting natural drainage so that excess water was contained at the surface. Potential reductions in site productivity arising from such activity can be minimized through the proper selection of equipment and the timing of its use to ensure that poorly drained sites are logged during freeze-up periods.

Compaction affected 30% of the unbulldozed portion of cutovers. Softwood regeneration on such areas tends to remain sparse and suppressed for much of the rotation period. In Newfoundland up to 4000 ha/yr may be affected in this manner. In terms of productivity, potential reductions in allowable annual cut of up to 0.36 m^3/ha/yr are possible.

While heavy logging slash occupied 29% of the unbulldozed cutover and may cause patchiness in the developing stands, it did not appear to be a major barrier to natural tree establishment. However, dense slash may pose a problem to forest management aimed at artificially restocking cutovers and may require that some form of treatment be undertaken to facilitate silvicultural operations.

In the final analysis skidder logging operations following conventional procedures create ground disturbances which could result in substantial site deterioration and reductions in long-term site productivity. Consequently, every effort must be made, especially under intensive forest management, to minimize impacts by reducing site damage at the operational stage in timber harvesting.

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